Wind Energy Validation Using Available Wind Potential

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Abstract—**This paper analyzes the probability distribution of wind speed data recorded by Maharashtra Energy Development Agency (MEDA) wind farm at Ahmednagar (India). The main objective is to validate the wind energy probability by using probability distribution function (PDF) of available wind potential. The wind speed is measured with the help of three anemometers S30, S45, S60 placed at 30 m, 45 m, and 60 m height. Mean values are recorded and stored for every hour using a Data logger. For accounting Wind Turbine Generator (WTG) tower height, data recorded from S60 anemometer at 60 m height is used for analysis purpose. To estimate the wind energy probability, hourly wind speed data for one year interval is selected. Weibull distribution is adopted in this study to best fit the wind speed data. The goodness of fit tests based on the Probability density function (PDF) is conducted to show that the distribution adequately fits the data. It is found from the curve fitting test that, although the two distributions are all suitable for describing the probability distribution of wind speed data, the two-parameter weibull distribution is more appropriate than the lognormal distribution**.

Index Terms— **probability distribution function, weibull distribution, maximum likelihood, lognormal distribution, goodness of fit, wind energy probability**

I. Introduction

Wind power is the fastest growing renewable energy source in the world. The Department of Energy (India) has recently presented detailed plan to produce 20 % of all power using wind turbines by 2015. The benefits are clear; wind power produces emission-free energy and runs on an unlimited, free fuel [1]. Like the weather in general, the wind can be unpredictable. It varies from place to place, and from moment to moment. Because it is invisible it cannot be easily measured without special instruments. Wind is a diffuse energy source which cannot be contained or stored for use elsewhere or at other time. It challenges us to harness it, but it first demands considerable study. Wind resource evaluation is a critical element in projecting turbine performance at a given site. Most wind maps are based on wind speed measurements at a relatively low height of 50 m. Since wind speed increases with higher altitudes, the wind resource available at altitudes higher than 50 m may be suitable for modern wind energy harnessing technologies. The energy available in a wind stream is proportional to the cube of its speed, which means that doubling the wind speed increases the available energy by a factor of eight. Furthermore, the speed wind varies with the time of day, season, height above ground, and type of terrain [2].

II. WIND FARM SITE SPECIFICATIONS

The data for this study was obtained from the wind farm of MEDA at Kavdya Dongar site at Supa in Ahemadnagar, Maharashtra (India). The project activity involves 59 windmills of 1000 KW capacity each of Suzlon make 3 phase 50Hz, 690V stepped up to 33 KV and connected to grid through common metering to deliver wind energy to rural location by Maharashtra State Electricity Transmission Company Limited.(M.S.E.T.C.L.) Substation at Supa, 132/33 KV, 25 MVA transformers capacity. WTG used having two stage generators SG1 operates when wind speed is more than 2.5 m/s and SG2 generates power when wind speed is more than 3.5 m/s. Figure 1 shows nonlinear relationship between the power output of the WTG and the wind speed. The relation can be described by the operational parameters of the WTG. The hourly power output can be obtained from the simulated hourly wind speed. The commonly used parameters are the cut-in speed (*2.5 m/s*), the rated speed (*15 m/s*), the cut-out speed (*20 m/s*), and rated power (*1000 w*) of a WTG unit respectively. Asynchronous generator with pitch control features with gear box and three blades of FRP machine mounted on lattice type G.I. Tower of 60 meter height with step up transformer and protection systems [3].

Wind speed is measured using a cup type anemometer in meter per second. Three anemometers S30, S45 and S60 placed at 30 m, 45 m, 60 m height, mean values at each hour were recorded and stored using a Data Logger. The data was collected daily starting 1st Jan 2008 until 31st Dec 2008 (One Year). However, there are some missing data for several days in May and August. The average wind speed measurement in May and August will be placed for missing data. Turbine performance values are dependent on manufacturer provided power curves, which may not accurately model real turbine performance at this site. In addition, several simplifications are made to the models utilized for power calculations. But ultimately the results of this study should be considered as estimates and not accurate predictions of wind behavior and turbine performance at Supa site.

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III. Characteristics of the Weibull Distribution

The weibull distribution is widely used in reliability and life data analysis due to its versatility [4]. The weibull distribution function is three-parameter function. Probability of wind speed "*h*" during any time interval is given by (1).

$$h(v)=\left(\frac{k}{c}\right)*\left(\frac{v-\gamma}{c}\right)^{(k-1)}*e^{-\left(\frac{v-\gamma}{c}\right)^{k}} \quad \text{For } 0 < v < “ \qquad (1)$$

Various parameters of (1) are shape parameter "*k*" scale parameter "*c*" and location parameter "ã". In this paper three parameter weibull distribution is converted into two parameter by setting location parameter "ã" equal to zero. Therefore (1) three parameter model becomes the two parameter model (2).

$$h(v)=\left(\frac{k}{c}\right)*\left(\frac{v}{c}\right)^{(k-1)}*e^{-\left(\frac{v}{c}\right)^{k}} \quad \text{For } 0 < v < “ \qquad (2)$$

Depending on the values of the parameters, the weibull distribution can be used to model a variety of life behaviors. We will now examine how the values of the shape parameter "*k*" affect such distribution characteristics as the shape of the PDF curve, the reliability and the failure rate. The weibull shape parameter "*k*" is also known as the slope. This is because the value of "*k*" is equal to the slope of the regressed line in a probability plot. Different values of the shape parameter can have mired effects on the behavior of the distribution. In fact, some values of the shape parameter will cause the distribution equations to reduce to those of other distributions. For example, when $k = 1$, the *PDF* of the three-parameter weibull reduces to that of the two-parameter exponential distribution. The parameter "*k*" is a pure number and it is dimensionless [4].

IV. Results and Discussion

a) Wind Speed

Tower height of WTG used for analysis energy is 60 meter; therefore, wind speed measured by anemometers S60 at 60 meter height is used for all calculation. Mean values per hour of wind speed are recorded. Figure 1 shows plot of yearly wind flow recorded. The histogram of one year wind velocity at this site is plotted Figure 2, which indicates that frequency of wind speed is more from 4 m/s to 15 m/s. Probability of wind flow is plotted for one year duration look like weibull characteristic shown in Figure 3.

b) Goodness of Fit

In order to verify the goodness-of-fit of the distribution model of wind speed data observations, the Probability density function (PDF) goodness of fit test should be conducted. Here confidence level is taken to be 95 %. Besides that the probability plot can also be conducted. The weibull distribution provides a close approximation to the probability laws of many natural phenomena.

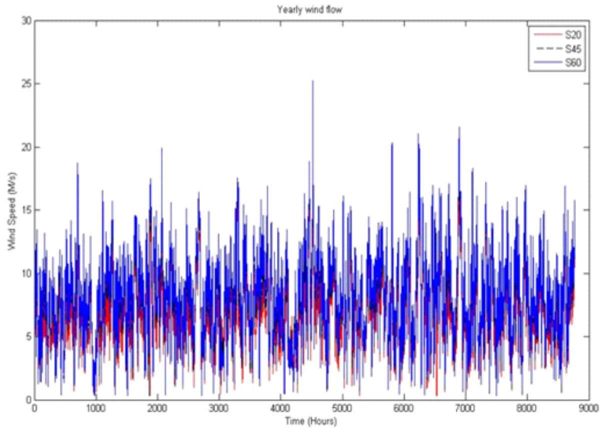

Figure 1.Measured plot of yearly Wind Flow.

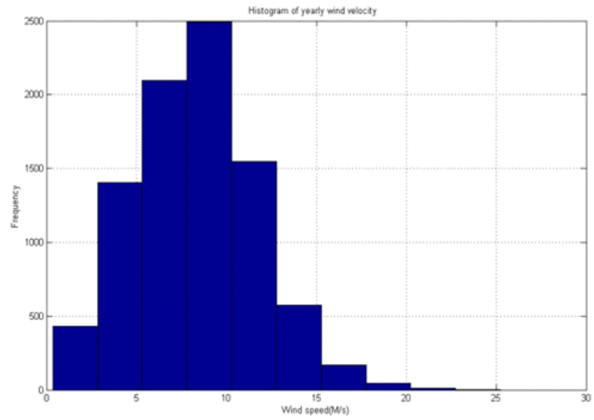

Figure 2.Histogram of Yearly measured wind data.

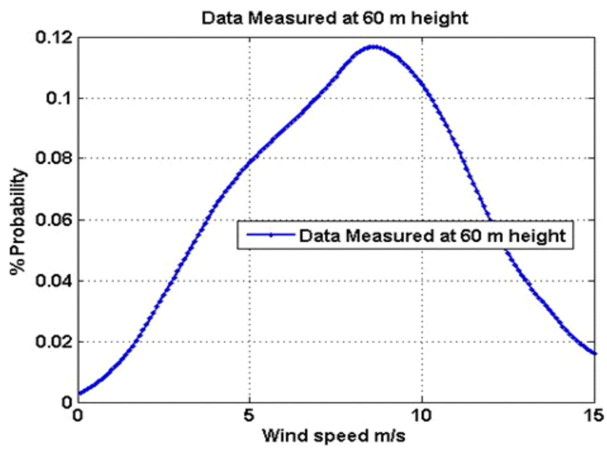

Figure 3. Probability of wind flow for one year.

The lognormal distribution may also be one of the most versatile distributions. In terms of life testing and reliability, the lognormal distribution is known as a serious competitor to the weibull distribution [5]. In recent years most attention has been focused on weibull distribution method for wind energy applications not only due to its greater flexibility and simplicity but also because it can give a good fit to experimental data.

The wind speed variation is best described by the weibull probability distribution function. Figure 4 shows curve fitting for measured data as weibull and lognormal fit. It is important

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to examine other statistics and plots to make a final assessment of normality. For assessment confidence level is taken up to 95 % significance level, all tests results shown in Table I support the conclusion that the two-parameter weibull distribution with scale parameter (c) = 0.00241 and shape parameter (k) = 2.686 provides a good model for the distribution of wind speed data.

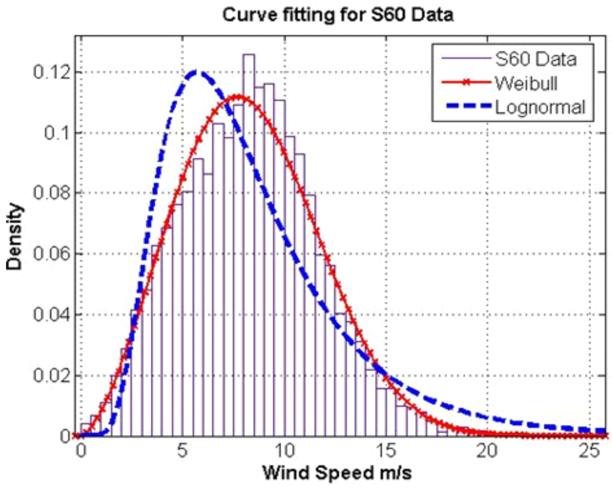

Figure 4. Curve fitting for weibull and lognormal.

While for lognormal distribution with scale parameter (μ) = -6.14963 and shape parameter (ó) = 2.97577, for the PDF test are all less than confidence level of 95 %, indicating that the data does not support a lognormal model [6]. Figure 4 shows that parameter estimates of the two-parameter weibull distribution are more appropriate compared with lognormal distribution.

TABLE I.
PARAMETER COMPARISON OF THE TWO DISTRIBUTIONS MODEL

Distribution	Weibull	Lognormal
Log likelihood	-23118.8	-24139.1
Domain	$0 < y < \infty$	$0 < y < \infty$
Mean	8.25278	8.45722
Variance	11.7346	21.3338
scale parameter	C= 0.00241	μ= -6.14963
shape parameter	K= 2.686	σ = 2.97577

Wind Speed Variation with Height

The variation in wind speed with elevation influences both the assessment of wind resources and the design of wind turbines. First, the assessment of wind resources over a wide geographical area might require that the anemometer data from a number of sources be corrected to a common elevation, second from a design aspect, rotor blade fatigue life will be influenced by the cyclic loads resulting from rotation through a wind field that varies in the vertical direction.

Thus, a model of the wind speed variation with height is required in wind energy applications. Figure 5 shows some of the wind speed variation with height that is used to predict the variation of wind speed with vertical elevation.

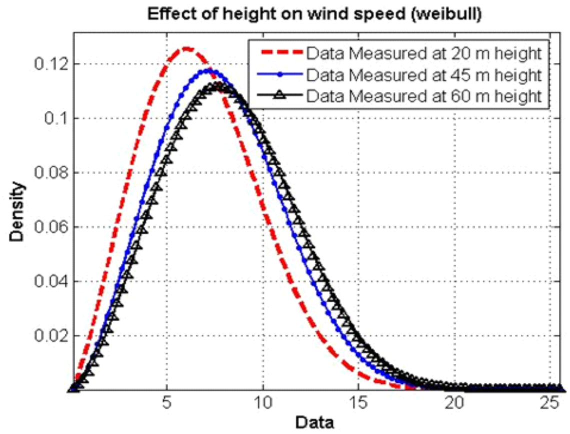

Figure 5. Effect of height on wind speed (for weibull distribution)

CONCLUSION

This paper validates probable power generation using a comparative assessment of methods for wind speed data obtained from the MEDA at Kavdya Dongar Site, by using weibull distribution. It is found from the goodness of fit test that the two-parameter weibull distribution is better than the normal and lognormal model.By analyzing recorded data at various heights it is found that a 60 m height is better for harnessing wind power with selected W.T.G.. Further, extension of the analysis will allow the validation of the trends, average speeds, and energy values observed for the last year.

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